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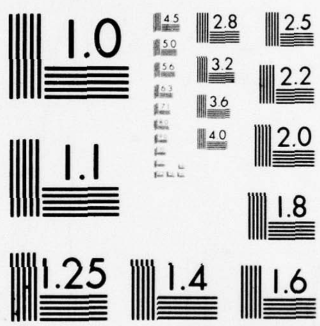
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ON THE QUESTION OF STATIC LONGITUDINAL STABILITY OF MOTION FOR A WING SYSTEM OF FINITE SPAN ABOVE A SOLID SCREEN

by

N. B. Plisov, V. K. Treshkov

EDITED TRANSLATION

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В в	*В в*	V, v	Т т	*Т т*	T, t
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Д д	*Д д*	D, d	Ф ф	*Ф ф*	F, f
Е е	*Е е*	Ye, ye; E, e*	Х х	*Х х*	Kh, kh
Ж ж	*Ж ж*	Zh, zh	Ц ц	*Ц ц*	Ts, ts
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И и	*И и*	I, i	Ш ш	*Ш ш*	Sh, sh
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К к	*К к*	K, k	Ъ ъ	*Ъ ъ*	"
Л л	*Л л*	L, l	Ы ы	*Ы ы*	Y, y
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Н н	*Н н*	N, n	Э э	*Э э*	E, e
О о	*О о*	O, o	Ю ю	*Ю ю*	Yu, yu
П п	*П п*	P, p	Я я	*Я я*	Ya, ya

*ye initially, after vowels, and after ъ, ь; e elsewhere. When written as ё in Russian, transliterate as yё or ё. The use of diacritical marks is preferred, but such marks may be omitted when expediency dictates.

GREEK ALPHABET

Alpha	Α	α	Nu	Ν	ν
Beta	Β	β	Xi	Ξ	ξ
Gamma	Γ	γ	Omicron	Ο	ο
Delta	Δ	δ	Pi	Π	π
Epsilon	Ε	ε ϵ	Rho	Ρ	ρ ϱ
Zeta	Ζ	ζ	Sigma	Σ	σ ς
Eta	Η	η	Tau	Τ	τ
Theta	Θ	θ ϑ	Upsilon	Τ	υ
Iota	Ι	ι	Phi	Φ	φ ϕ
Kappa	Κ	ϰ κ	Chi	Χ	χ
Lambda	Λ	λ	Psi	Ψ	ψ
Mu	Μ	μ	Omega	Ω	ω

RUSSIAN AND ENGLISH TRIGONOMETRIC FUNCTIONS

Russian	English
sin	sin
cos	cos
tg	tan
ctg	cot
sec	sec
cosec	csc
sh	sinh
ch	cosh
th	tanh
cth	coth
sch	sech
csch	csch
arc sin	$\sin^{-1}$
arc cos	$\cos^{-1}$
arc tg	$\tan^{-1}$
arc ctg	$\cot^{-1}$
arc sec	$\sec^{-1}$
arc cosec	$\csc^{-1}$
arc sh	$\sinh^{-1}$
arc ch	$\cosh^{-1}$
arc th	$\tanh^{-1}$
arc cth	$\coth^{-1}$
arc sch	sech^{-1}
arc csch	csch^{-1}
rot	curl
lg	log

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ON THE QUESTION OF STATIC LONGITUDINAL STABILITY OF MOTION FOR A WING SYSTEM OF FINITE SPAN ABOVE A SOLID SCREEN

N. B. Plisov, V. K. Treshkov, Department of Fluid Mechanics

Let us examine the longitudinal motion of a "wing-tail" complex with speed u_0 above a solid surface (Fig. 1). We will consider the wings to be thin and rectangular in shape in a plane. The tail assembly may have a dihedral angle. A study of the dynamic stability of the wings' motion system in tandum without consideration of the wings' interaction in the system in tandum was accomplished in work [1]. In the coupled coordinate system ox, y, z, whose origin is at the center of gravity of the complex, the equations of longitudinal motion have a form which is similar to the equations of motion of an airplane in a boundless fluid [2]:

$$\left.\begin{aligned} &\frac{G}{g}\cdot\frac{d\gamma}{dt}u_0 = Y - G \\ &J_z\frac{d^2\varphi}{dt^2} = M_z \end{aligned}\right\}, \qquad (1)$$

where G - the weight of the wings; J_z - the inertial moment of their masses; ϕ - the trim angle of the complex; γ - the trajectory angle.

Let us accept that the center of gravity of the complex coincides with the middle of the wing. We assign the subscript 1

to the geometric and aerodynamic characteristics of the wing and subscript 2 to the tail assembly. We can present the lift Y and moment M_z with movement close to a solid surface in accordance with work [3] in the form

$$\left.\begin{aligned} y &= C_y \frac{\rho u_0^2}{2} S_1 = \left(C_y^0 + C_y^{\varphi}\varphi + C_y^{h} h + C_y^{\dot\varphi}\dot\varphi + C_y^{\dot h}\dot h\right)\frac{\rho u_0^2}{2} S_1 \\ M_z &= m_z \frac{\rho u_0^2}{2} S_1 b_1 = \left(m_z^0 + m_z^{\varphi}\varphi + m_z^{h} h + m_z^{\dot\varphi}\dot\varphi + m_z^{\dot h}\dot h\right)\frac{\rho u_0^2}{2} S_1 b_1 \end{aligned}\right\}. \qquad (2)$$

In formulas (2)

$$h = \frac{2\bar h}{l_1}, \qquad \dot h = \frac{1}{u_0}\cdot\frac{d\bar h}{dt}, \qquad \dot\varphi = \frac{b_1}{u_0}\cdot\frac{d\varphi}{dt},$$

and the aerodynamic force coefficients and moments are referred to the area and chord of the main wing.

Employing the usual method of small perturbations to study stability, from system (1) we can obtain the characteristic equation of the disturbed motion of a wing system above a solid screen:

$$\lambda^4 + a_1\lambda^3 + a_2\lambda^2 + a_3\lambda + a_4 = 0,$$

where coefficients a_1, a_2, a_3, a_4 depend on the weight, moment of inertia, and aerodynamic characteristics of the wing system. In particular, the expression for the free term has the form

$$a_4 = m_z^{\varphi} C_y^{h} - m_z^{h} C_y^{\varphi},$$

where $C_y^h < 0$, $C_y^{\varphi} > 0$.

Motion is stable if all the roots of the characteristic equation have a negative real portion. This is observed when satisfying a number of conditions a_1, a_4 [2]. One of them consists of

$$a_4 > 0 \qquad (3)$$

or, for our case

$$R = \frac{m_z^h}{C_y^h} - \frac{m_z^y}{C_y^y} > 0. \tag{4}$$

In work [2] it is shown that non-satisfaction of inequality (3) leads to a periodic instability of motion and that this condition coincides with the condition of static stability of the aircraft. By analogy, we will call (4) the condition of static longitudinal stability of a wing system close to a solid surface.

To determine R we can use the method of calculating the hydroaerodynamic characteristics of a system of wings of finite span which is moving above a screen [4]. A substantial feature of this method is consideration of the interaction of the wings. Work [4] presents data on the so-called coefficients of interaction K_1, K_3, K_4; knowing them as well as the characteristics of the wing and tail assembly separately, it is not difficult to calculate the characteristics of the complex as a whole. In accordance with the characteristics for individual wings, let us use the results of the calculations from linear theory [5], [6], i.e., we will consider $C_{y_1}^{\alpha}(h)$, $m_{z_1}^{\alpha}(h)$, $C_{y_2}^{\alpha}(h)$, $\bar{m}_{z_2}^{\alpha}$ known. Given the flight lift coefficient of system C_y^0 and considering the balancing conditions, we determine the setting angle of the first δ_1 and the second δ_2 wings. The equations of the balancing conditions have the form

$$\left.\begin{aligned} C_{y_1}^{0} + C_{y_2}^{0} + C_{y_2}^{h} C_{y_1}^{0} K_1 &= C_y^{0} \\ m_{z_1}^{0} + m_{z_2}^{0} + m_{z_2}^{h} C_{y_1}^{0} K_1 &= 0 \end{aligned}\right\}, \tag{5}$$

where

$$
\left.\begin{aligned}
&c_{y_1}^{0} = c_{y_1}^{\varphi}\delta_1 \approx c_{y_1}^{\alpha}\delta_1, \quad c_{y_2}^{0} = c_{y_2}^{\varphi}\delta_2 \approx c_{y_2}^{\alpha}\frac{S_2}{S_1}\delta_2 \\
&m_{z_1}^{0} = m_{z_1}^{\varphi}\delta_1 \approx m_{z_1}^{\alpha}\delta_1 \\
&m_{z_2}^{0} = m_{z_2}^{\varphi}\delta_2 - c_{y_2}^{0} B\frac{\lambda_1}{2} \approx \left[m_{z_2}^{\alpha}\frac{b_2}{b_1} - c_{y_2}^{\alpha} B\frac{\lambda_1}{2}\right]\frac{S_2}{S_1}\delta_2 \\
&c_{y_2}^{\dot{h}} \approx c_{y_2}^{\alpha}\frac{S_2}{S_1} \\
&m_{z_2}^{\dot{h}} \approx \left[m_{z_2}^{\alpha}\frac{b_2}{b_1} - c_{y_2}^{\alpha} B\frac{\lambda_1}{2}\right]\frac{S_2}{S_1} \\
&B = \frac{2\bar{B}}{\ell_1}
\end{aligned}\right\}, \qquad (6)
$$

K_1 - the coefficient of interaction.

In formulas (5) and (6) $c_{y_1}^{0}$, $c_{y_2}^{0}$, $c_{y_1}^{\varphi}$, $c_{y_2}^{\varphi}$ etc. - the coefficients referred to the same geometric dimensions (to the dimensions of the wing); $c_{y_i}^{\alpha}$ and $m_{z_i}^{\alpha}$ $(i = 1,2)$ - are taken directly from the calculations from linear theory relative to the middle of each wing and referred to its geometric dimensions. Substituting relationships (6) in (5) and solving this system, we find δ_1 and δ_2.

Subsequently, the calculation is conducted in accordance with the formulas presented in work [4]. The derivatives from the aerodynamic characteristics of the wings for flight altitude are calculated from formulas of the type

$$
c_{y_i}^{h} = \frac{\partial c_{y_i}^{\alpha}}{\partial\left(\frac{1}{h}\right)}\frac{1}{h}\delta_i, \qquad m_{z_i}^{h} = \frac{\partial m_{z_i}^{\alpha}}{\partial\left(\frac{1}{h}\right)}\frac{1}{h}\delta_i .
$$

In calculations of the value R, it is also necessary to keep in mind that the corrections of interaction are determined first relative to the axis which passes through the bound vortex which replaces the first wing and, in the final result, characteristics relative to the center of gravity are necessary. Formulas for the recalculation of the aerodynamic characteristics are presented in [4].

The results of the calculations are presented in Figs. 2-4. Analysis of the results shows that the relationship of the tail-unit and wing spans ($K_\ell = \ell_2/\ell_1$) has a substantial influence on the stability of the system and the nature of the dependences of criterion R on various parameters. With some values of K_ℓ, an increase in the rise of the tail unit above the wing ($H = 2\bar{H}/\ell_1$) or the placement of a V-empennage leads to a considerable increase in the static stability of the complex. The value of R also depends on the spacing of the wings B. There is an expressed maximum R(B) for a number of values of H. In the versions which were investigated ($K_\ell = 1{,}0$), an increase in the flight lift coefficient C_y° (otherwise - a decrease in flight speed) led to a noticeable decrease in stability and an increase in the wing aspect ratio and the tail area with other dimensionless geometric parameters being equal - to an increase in the value R.

$\lambda_1 = 2 \qquad \psi_2 = 0 \qquad C_y^\circ = 1{,}0 \qquad \frac{S_2}{S_1} = 0{,}5 \qquad h_0 = 0{,}3$

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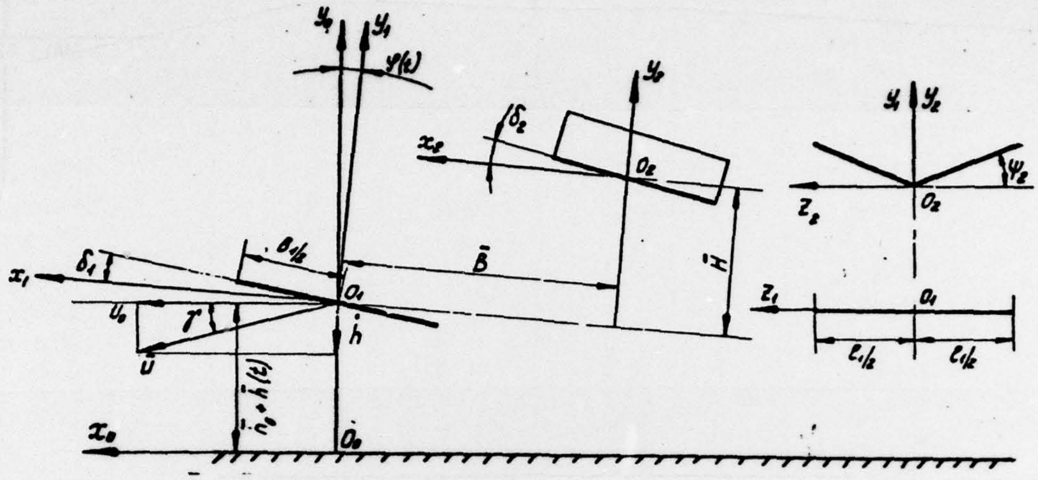

Fig. 1. Coordinate systems and geometric parameters.

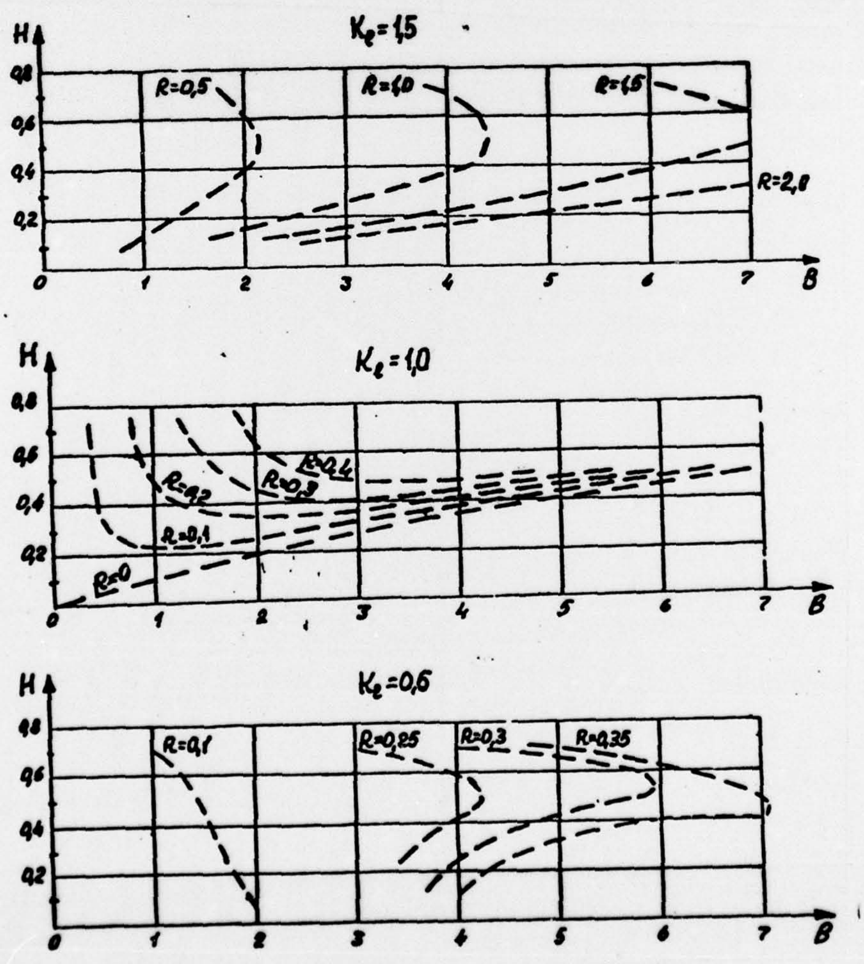

Fig. 2. Effect of the elevation of the tail unit H and the spacing of the wings B on the static stability of the system.

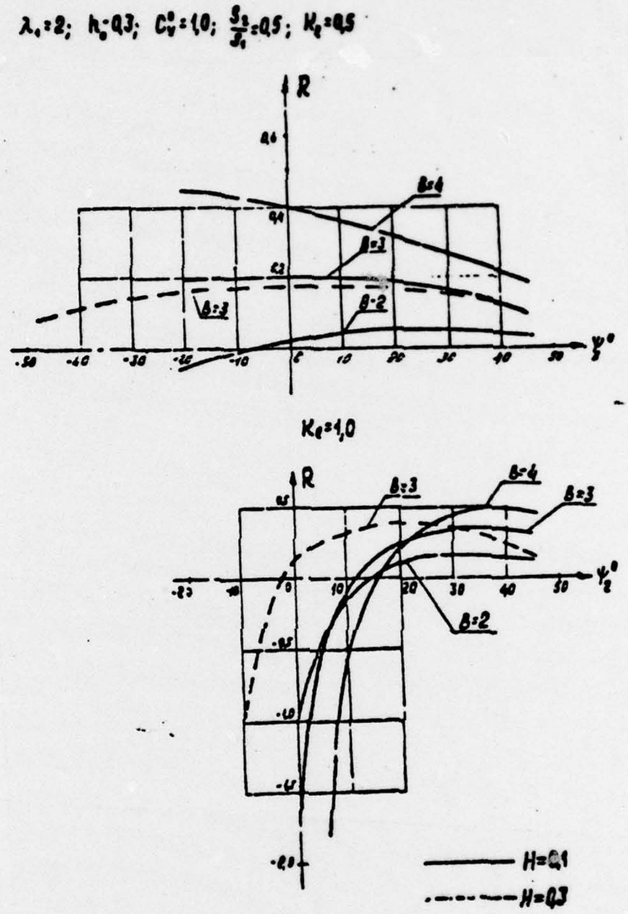

Fig. 3. Effect of the dihedral angle of the "tail unit" on static stability.

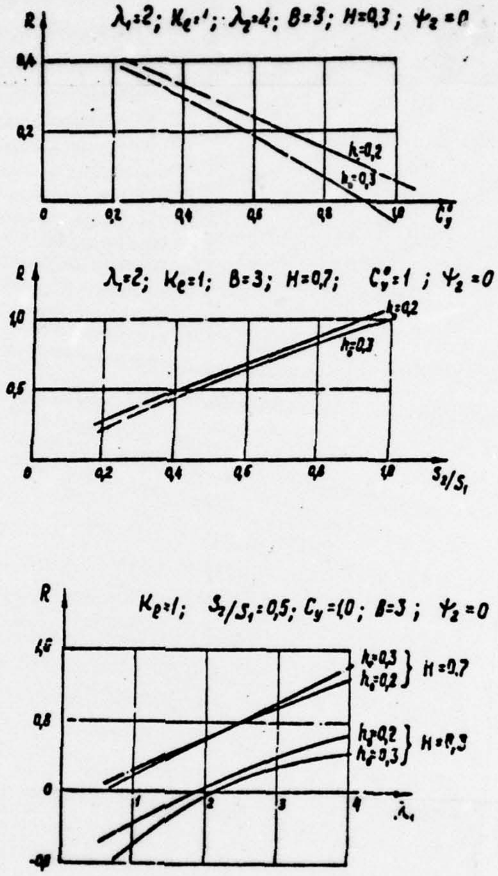

Fig. 4. Effect of C_y^0, area of the tail unit, and "wing" aspect ratio on the value R.

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